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Addressing Iran's water crisis: The role of isotope hydrology in sustainable management

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Abstract

Despite possessing a more advanced water management system than many Middle Eastern countries, Iran is experiencing a severe water crisis due to the escalated demand, overexploitation of groundwater, frequent droughts, salinization, and unsustainable management practices. This study provides a comprehensive assessment of Iran’s current water resources, identifies key challenges, and examines the main drivers of water scarcity. It also investigates alternative solutions, including wastewater treatment and desalination, which can help reduce reliance on conventional freshwater resources by promoting water recycling and utilizing the country’s extensive saline water reserves. The effective management of water resources in Iran requires a thorough understanding of the water cycle, the implementation of sound management strategies, and the development of suitable infrastructure. However, the absence of reliable hydrological data-such as information on water sources, withdrawals, and environmental rights poses significant obstacles to sustainable management. The application of environmental isotope technologies offers a promising approach, enabling researchers to trace the origin, recharge, age, and movement of water within the hydrologic cycle. Stable isotopes like deuterium and oxygen-18 serve as valuable indicators of water circulation, providing cost-effective and insightful data for water resource investigations. Despite the critical nature of Iran’s water crisis, the adoption of isotope hydrology methods remains limited, highlighting the need for greater awareness and integration of these techniques. This study emphasizes the use of stable water isotopes to deliver essential information for sustainable water management and informed decision-making regarding water allocation and conservation.

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Introduction

Overview of the water resources in Iran

The average annual precipitation in Iran is estimated at 228 mm, although significant regional variations exist, classifying much of the country as arid and semi-arid (Karandish et al., 2018; Naderi et al., 2024; Sotoudeheian et al., 2022). Precipitation varies from 50 mm in parts of the central water basin to more than 1,500 mm in some coastal areas near the Caspian Sea. Around 70% of precipitation falls as rain, and the remaining 30% falls as snow (Azhdari et al., 2022; Najafi Tireh Shabankareh et al., 2024). Figure 1 illustrates the distribution of precipitation in Iran from 2010 to 2019 (Iran, 2019; Water, 2021).

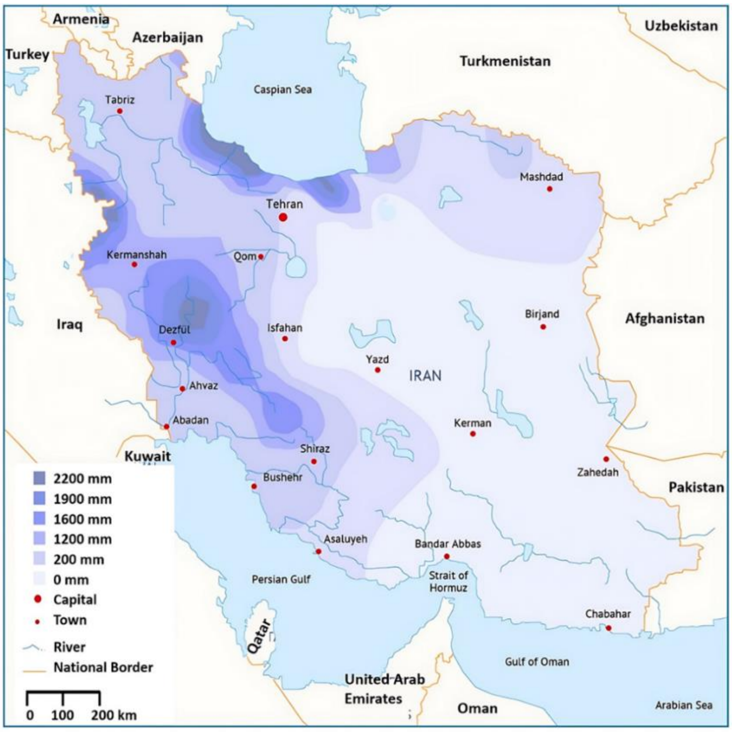

Figure 1. Precipitation distribution (mm) in Iran (2010-2019). (Source: Ministry of Energy, Iran) @Fanack water. Retrieved and modified from: water.fanack.com. 12/2023

It is estimated that 70% of the 406 billion cubic meters (BCM) of annual precipitation evaporates before it reaches the rivers (Esmaeilion et al., 2021; Norouzi, 2020). Approximately 78 BCM of the total 130 BCM of long-term renewable yearly freshwater resources represent the portion of surface runoff that remains within the country, while the remaining runoff volume flows out of the country (Gholipour, 2025; Sung, 2023). Part of this water feeds underground aquifers, with approximately 90% used for agriculture, and the remaining portion allocated for drinking water supply and industrial purposes (Fao, 2008; Mirzavand et al., 2020; Moridi, 2017). Compared to 1956, when 7,000 m^3 of water per person was available, today, only approximately 1,500 m^3 per person is available (Iran 2019). The distribution of freshwater access in Iran (Zekri 2020) is shown in Figure 2.

Iran has six primary and thirty-one secondary basins. These are the six primary basins in the country (Shown in Figure 3): the Central Plateau (Markazi) in the center covering 824,400 km^2, the Lake Urmia basin in the northwest spanning 51,800 km^2, the Persian Gulf and the Gulf of Oman basin in the west and south covering 424,500 km^2, the Eastern Border basin in the east (103,200 km^2), the Qareh Qum basin in the northeast covering 44,200 km^2 (formerly known as Sarakhs), and the Caspian Sea basin in the north (Khazar) covering 174,000 km^2. These basins are inland, except for the Persian Gulf and the Gulf of Oman. The Gulf of Oman basin encompasses a quarter of the country, while the Persian Gulf holds more than half of the country's renewable water resources. In contrast, the Markazi basin, which includes more than half of the country, has less than one-third of all renewable water resources. Situated approximately 22 meters below sea level, the Caspian Sea extends over an area of 424,240 km^2, making it the world's largest landlocked body of water (Alizadeh, 2021; Moridi, 2017; Zehzad et al., 2002; Zekri, 2020).

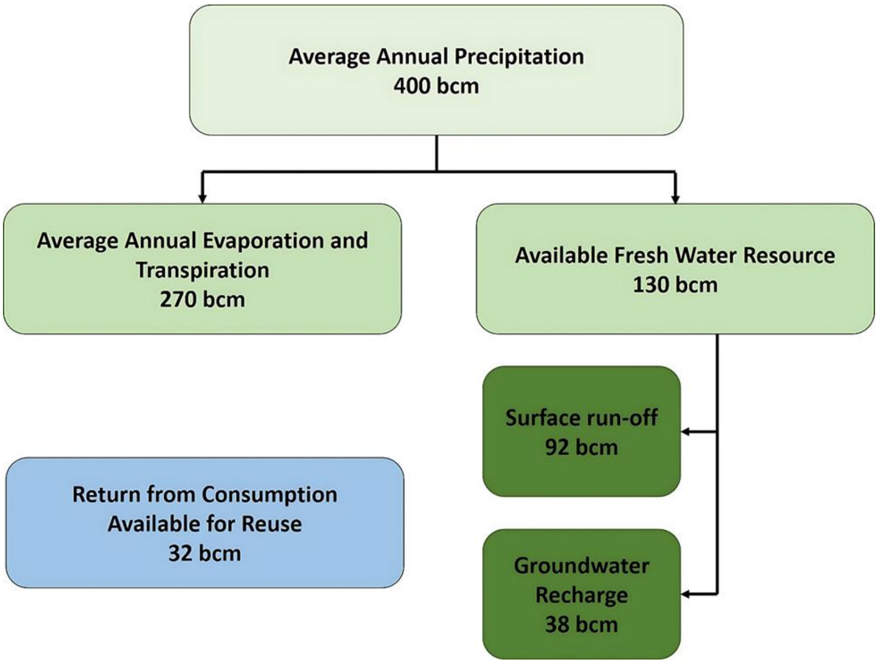

Figure 2. Breakdown of freshwater availability in Iran. Inspired by water.fanack.com. 12/2023

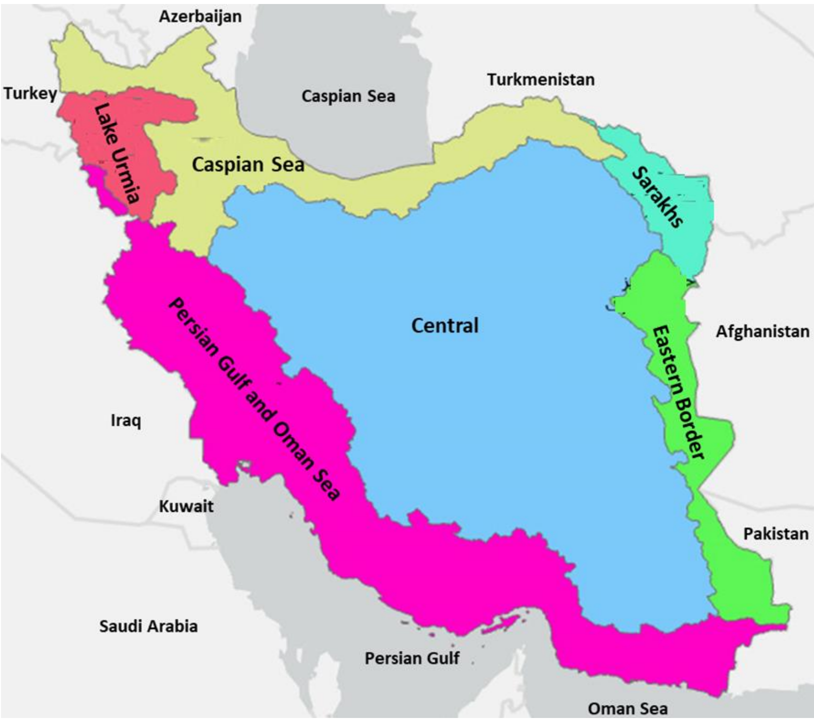

Figure 3. Location of Iran's primary basins. Inspired by (Rajabi, 2025)

Iran's Water Scarcity

Iran is one of the 24 most water-scarce countries (Bogheiry, 2022; Kayhanian et al., 2016), and unfortunately, Iran's drought problem has transformed into a natural phenomenon, impacting a significant portion of the country to different extents (Fani et al., 2016; Ghamghami et al., 2019; Karbalaee, 2010; Madani et al., 2016). Public consumption is roughly double the global average (Madani et al., 2016; Talebi, 2023), and data indicate that 11 megacities, with a combined population of 37 million, are facing water stress (Moridi, 2017). According to estimates, Iran consumes an average of 96 BCM of water annually (Azam et al., 2012; Khatibi et al., 2019). This figure exceeds the country's total renewable water resources (89 BCM) and is 80% higher than the 53 BCM scarcity threshold limit. Nearly two-thirds of Iran's irrigated lands are supplied with water from groundwater, which fulfills over 43% of the country's agricultural needs (Marc et al., 2015; Yazdandoost, 2016). The national groundwater overexploitation is estimated at 5.6 BCM annually, exceeding the total infiltration of 58 BCM by 63.8 BCM groundwater abstraction (Khaki 2020). As less surface water is available in the central basins, there is greater overexploitation in that area (Van Camp et al., 2010).

The country primarily dependents on groundwater, which is depleting at an alarming rate. The amount of water available per capita has drastically decreased recently (Amiraslani et al., 2020; Madani, 2014). The lack of accurate data on water sources and withdrawals presents a significant challenge in evaluating Iran's water situation. Rivers and wetlands, for example, are not represented in the environmental rights statistics (Al-Abidin, 2022; Yamada, 2019). The inefficient water consumption in agriculture, a sharp decrease in aquifers as a result of excessive use of current water resources, inadequate wastewater disposal systems in urban and industrial areas causing water source contamination, various consumptions threatening water ecosystems, high government water subsidies, increased cost of new water resource development and supply projects, unforeseen events like severe floods and droughts, lack of systematic studies to assess the impact of climate change on water resource management, and insufficient infrastructure to promote favorable economic conditions in the water sector are some of the key issues contributing to unsustainable water management in Iran (Khosravi et al., 2019; Nazari et al., 2018; Yazdandoost, 2016; Zarrineh et al., 2014).

The Iranian government should focus on conserving water and using it efficiently in order to effectively address the water crisis.
Water-intensive activities can be minimized by upgrading irrigation systems, expanding greenhouses, and optimizing cropping patterns. The processes of desalination and wastewater treatment are crucial in addressing the issue of water scarcity, as they convert saltwater and wastewater into valuable resources (Ali et al., 2022). Iran initiated water desalination in 1960 with a small desalination plant on the island of Khark (Emami et al., 1977). Approximately 73 water desalination facilities, mainly located in the southern part of the country, were operational in 2020, with a combined capacity of around 420,000 m3/day of fresh water. To serve 45 million people across 17 provinces, the government planned to construct an additional 50 desalination units in the same year. Detailed expenses, sources of funding, and environmental impacts of these desalination plants are still poorly documented (Caldera et al., 2019). Despite Iran's extensive efforts to treat wastewater, the reuse of treated wastewater is not commonly used in urban areas, mainly due to cultural factors. In recent years, municipalities have increasingly used treated wastewater for urban services such as maintenance and green development (Moridi, 2017). In 2019, there were 190 water treatment plants in operation, five of these facilities located in Tehran, providing water to 12 million people. However, due to inadequate solid waste and wastewater management, Iran's water resources are polluted (Figure 4) (Ardalan et al., 2019). Without any treatment, about two-thirds of the wastewater from industrial plants is

discharged into surface and groundwater resources (Foster et al., 2011; Piadeh et al., 2014).

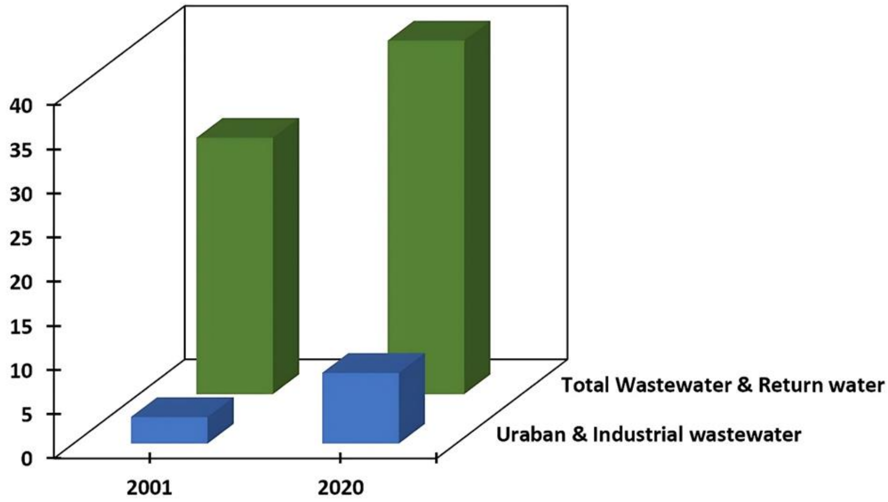

Figure 4. Major indicators for Iran's water resource pollution showing the increase between 2001 and 2020 (Water 2021)

Sustainable Approach to Water Resource Management

Based on the above-mentioned problems, it is necessary to develop a new water resource management policy that guarantees people's livelihood. In addressing the water crisis, shifting attitudes toward water management could lead to significant improvements, and our future depends on it. It could simply be said that Iran needs a policy of "sustainable development in water management" to maintain its stability, a recognized approach to addressing the global water challenges. The world, including Iran, needs a water management model that guarantees the preservation of water resources for future generations while also allowing for the current utilization of water (Aryanfar, 2020). The pressure on water resources has been exacerbated by population growth and climate change. Therefore, the traditional approach is no longer applicable, and there is a need to adopt a more comprehensive approach to water management at the national, basin, and international levels. Increasing attention to water security and climate change presents a significant opportunity for scientists and policymakers to manage water resources effectively. The management of water resources should be strengthened through science-based policies so that a holistic mentality can be incorporated into the complex system of water management and appropriate decisions can be made (Khalkhali et al., 2018). Strengthening the relationship between science and policy will improve the management of water resources and ensure the social and economic development and efficiency of vital ecosystems in each country. In addition, effective water governance ensures water security, distribute water resources equitably, and avoid disputes. The government plays a crucial role in addressing this issue and should set a policy for water management.

Real-world problems are vast and complex and require tools and information from different fields to formulate solutions. For sustainable development policies in water management, Iran needs to rethink and review the requirements for science and technology in this field. Iran cannot create a knowledge base for implementing water management policies without changing its education, research, and technology systems. One of the most important tools for integrated water resource management is data on the hydrological cycle (Stewart, 2015). Unfortunately, insufficient information about the hydrological system makes it difficult to understand, especially concerning water resource management.

To preserve these valuable water resources for future generations, decisions on where water is abstracted, how much is used, and how it is managed must be based on accurate information as the probability of water shortage increases. Appropriate policies should be created based on the socio-economic and environmental features of each basin, given the growing complexity and integration of environmental, social, and economic functions.

Today, stable water isotopes play an impressive role in hydrological research as natural tracers for the effective and sustainable management of water resources. Around the world, isotope hydrology is a vital tool that gives us the necessary knowledge to make the best decisions now or in the future. Numerous well-researched and field-validated isotope techniques provide practical instruments with recognized technological and financial advantages for assessing, developing, and managing water resources. It is worth noting that, in contrast to expensive traditional investigations, isotope studies are inexpensive, and a single analysis can provide a significant volume of information on the hydrological process. This technique involves using isotopes to analyze water sources, such as rivers, lakes, and groundwater. It helps to determine the age, origin, and quality of the water, which is crucial for developing effective strategies for managing and conserving water resources. Using isotopic hydrology, we can better understand the movement and distribution of water, identify potential sources of contamination, and make informed decisions about how to sustainably allocate and use water resources sustainably.

In light of this, this overview attempts to explain the necessity of using isotope hydrology in the management of Iran's water resources by illustrating the current state of water resource management in Iran, which is severely limited due to population growth, periodic droughts, climate changes, and unsustainable management of water resources.

Discussion

Groundwater is the most crucial source of water in Iran and accounts for nearly 60% of Iran's freshwater, so it plays an essential role in maintaining national water security (Samani, 2020). With a population of 84 million people, Iran ranks first in the Middle East regarding total water withdrawals by humans, and 34% of the unlimited water withdrawals in the region occur in this country (Ashraf et al., 2019). Based on the data published and analyzed from 2002 to 2015, it is clear that severe drought caused by extensive groundwater extraction threatens the stability of groundwater in Iran (Noori et al., 2021). Iran faces excessive groundwater withdrawal in 77% of its land area, which includes 23 of the country's 30 basins (Ashraf et al., 2021), and the extent of human use in Iran is more than three times the natural recharge of the basin (Ashraf et al., 2021; Noori et al., 2021), which has led to a significant decline in groundwater levels; this problem is reflected in the increasing number of dry wells across the country. Given the current status of groundwater depletion and the rising lack of surface water resources, maintaining irrigated agriculture and domestic water supplies will be a severe concern in the coming years (Ashraf et al., 2021).

Water Crisis

The water crisis is a significant impediment to food security in Iran (Madani et al., 2016; Zehtabian et al., 2010). This issue is primarily related to the energy requirements of a country that is currently under strict international sanctions and experiencing various socioeconomic, environmental, and geopolitical tensions (Hejazi et al., 2022; Pakravan-Charvadeh et al., 2020; Zamanialaei et al., 2023). The impact of the decline in the water table in Iran extends beyond water and food security (Khatibi et al., 2019). It has also impacted other areas of the environment, resulting in an increase in soil salinity across the country (Hamzekhani et al., 2016; Madani 2014). Furthermore, excessive groundwater withdrawal has led to ground subsidence, which affects soil stability. This issue is particularly significant in densely populated cities like Tehran, making them more vulnerable to earthquakes (Mahmoudpour et al., 2016). Without effective management practices, competition for limited groundwater resources will inevitably worsen due to excessive withdrawal, leading to further ground subsidence. This faulty process must be effectively addressed and understood.

In Iran, where the agricultural sector consumes more than 90% of the extracted water, and its efficiency is lower than that of other sectors (Zarei Ghorkhodi et al., 2022), urgent action is needed to improve water use. Such an approach is crucial for Iran's environmental security, which is expected to face increased pressure from prolonged natural and artificial droughts, as well as growing biodiversity and climate change.

Iran is currently experiencing a water scarcity crisis, with demand and consumption exceeding the country's water resources (Collins, 2017). This has led to the inability to meet the expectations of stakeholders and society. The causes of the water crisis include inefficient agricultural practices, indiscriminate use of pastures and forests, an increased number of state beneficiaries, high population growth, lack of effective and efficient water pricing policies, excessive and aggressive extraction of underground water resources, low levels of public literacy on water issues, absence of an active management paradigm, and changing factors related to climate change and its impacts (Afshar et al., 2019; Ketabchy, 2021; Madani, 2014; Madani et al., 2016). However, the primary cause of this bankruptcy is the absence of essential structural components required for sustainable resource management. To address water scarcity, Iran must prioritize reducing water consumption by adapting to new water resource conditions and increasing resilience before significant changes in water systems occur (Madani, 2014; Nazari et al., 2018).

To enhance water resources management, Iran needs to implement measures such as restricting water withdrawal from authorized wells, sealing unauthorized wells, adjusting the allocation of agricultural wells and treated wastewater for irrigation, prioritizing prohibited and critical areas for rehabilitation programs, artificially recharging aquifers, establishing advocacy groups for underground water users, promoting the establishment of local water markets, determining the cost of water, and altering cropping patterns while adopting a sustainable agricultural system (Ketabchy, 2022; Łabędzki, 2016; Shahraki et al., 2019; Tzanakakis et al., 2020).

Careful monitoring of water resources is essential for implementing effective management methods. However, this has not been well executed in developing countries due to its hidden nature and the lack of recognition of the human impact on water resources (Abbaspour 2011; Bernedo Del Carpio et al., 2021; Dungumaro et al., 2003).

Isotope hydrology

Since the environmental and water situation in Iran has changed significantly, there is a fundamental question to be answered: Is it necessary to change the country's current management approach to improve adaptation and resilience in the water sector? We think that the existing management system cannot combat water-related problems because it is the same management system that has caused them (Yazdandoost 2016).

According to various studies, the main reason for the inability to make appropriate water management decisions in Iran seems to be the lack of comprehensive data for future management decisions (Aryanfar 2020; Madani 2014; Mirnezami et al., 2017; Zarghami 2011). In Iran, despite the critical conditions in most watersheds, hydrological studies have been conducted for many years with a specific structure based on the nature of pristine watersheds. Even in the last decade, basic hydrological studies have not changed despite the increasing pressure and threats to the quantity and quality of freshwater resources in the past. The general practice of water management and policy in recent decades has primarily been based on the physical control of water in line with economic interests without attention to the internal relationships and complexity of the ecosystem, human society, and their interaction. One of the most critical actions needed is also the careful monitoring of water resources, which is effective and necessary to provide management methods and has not been well performed in developing countries due to its hidden nature and lack of recognition of the human impact on water resources.

The realization of social change in today's world undoubtedly requires attention to the scientific and technological bases and the creation of appropriate conditions for implementing these bases. The challenge for sustainable and integrated water development is recognizing changes in the advancement or invention of new technologies, institutional and policy laws, rules, and regulations.

It is necessary to achieve this goal using scientific techniques, such as stable isotope technology, for hydrological studies. Over the last two decades, isotope methods have been vital to the qualitative and quantitative evaluation of water resources. For example, in surface water studies, isotope techniques are used to quantify the dynamics of water bodies, leakage from lakes, reservoirs, and canals, stream and river flow rates, and rainwater runoff. The results of such studies can often yield information that is not available through other methods, and they tend to be considerably less expensive than traditional hydrologic methods (Yurtsever et al., 1993).

Isotope hydrology can be divided into two categories: artificial and environmental isotope hydrology. In artificial isotope hydrology, radioactive isotopes are introduced into the system under investigation, and isotope concentration changes are monitored. The latter has grown considerably in areas where fundamental hydrology data are limited. Due to natural processes in water bodies, environmental isotope hydrology can track isotopic changes and interpret them to solve particular hydrological problems based on a broad understanding of isotopic variations in nature. When natural conditions lead to observable changes in the isotopic content of different waters, which is usually the case, environmental isotopes can be applied to study regional hydrological problems (Sidle 1998).

As the chemical components of water, i.e., oxygen and hydrogen isotopes, are not affected by interactions with the aquifer material, they are, in a sense, the perfect geochemical tracers of water. However, the presence of carbon compounds in groundwater could lead to interactions with aquifer components, analyzing the results challenging (Edjah et al., 2017). The isotopic composition of natural waters varies due to various vital natural processes. The two most significant ones are condensation and evaporation. The light water molecules, $H_2{}^{16}O$, evaporate more quickly than those with heavy isotopes, such as deuterium (D) or oxygen-18 (^{18}O). As a result, compared to ocean water, evaporative water has less deuterium and oxygen-18 (Heydarizad et al., 2019). The heavier molecules condense preferentially as this atmospheric water vapor cools and condenses in clouds and precipitation. As a result, subsequent precipitation originating from the same original vapor mass will become increasingly depleted of deuterium and oxygen-18 (Araguás-Araguás et al., 2000; Webster et al., 2003). There should be a relationship between the isotopic composition of precipitation and the temperature at which it forms since the degree of condensation of a vapor mass is dependent on temperature. This temperature dependence leads to variations concerning latitude (precipitation at high latitudes is depleted compared to precipitation at low latitudes), altitude (the content of heavy isotopes in precipitation decreases with increasing altitude), and seasonal isotopes in precipitation (winter precipitation is more depleted in heavy isotopes compared to summer precipitation). Research on regional hydrology should pay particular attention to the last effect. The isotopic composition can be used, for example, to distinguish groundwater from recharge sites at different altitudes (Araguás-Araguás et al., 2000; Dansgaard, 1964).

In summary, in comparison to conventional hydrology, isotope hydrology has several benefits for the management of water resources. The origin, flow, and sustainability of water resources cannot be accurately determined using traditional hydrological techniques, although they can offer information on the amount and quality of water resources. On the other hand, isotope hydrology uses environmental isotopes that are both stable and radioactive to track the motions of water in the hydrological cycle. This method can offer vital information about underground water supplies, their sources of recharge, and the possibility of pollution or saltwater intrusion. In addition, isotope hydrology can be used to find potential underground reservoirs for geothermal plants, examine dam and reservoir leaks, and determine how vulnerable groundwater sources are to contamination (Jasechko 2019; Keesari et al., 2021; Tan et al., 2012; Verhagen 2003; Vitvar et al., 2005). Sustainable water resource management depends on making well-informed decisions about the extraction and use of water, which is made possible by the knowledge offered by isotope hydrology.

Numerous conclusions, can be made from the analysis of isotopic data. However, it should be noted that these methods require close cooperation with hydrologists to ensure correct application and optimal interpretation of isotope data. The most crucial first step is to precisely define the problem. Using standard hydrogeological study techniques can be as simple as stating which of numerous hypotheses is the most likely. The tenable hypothesis can then be indicated, or at the very least, some of the hypotheses proposed can be ruled out using the isotope approach.

The goal of isotope hydrology as an inspiring basic science is to create a fundamental understanding of the complex conditions of water-human systems, which will play an essential role in making water management decisions to maintain the stability of water systems. Undoubtedly, under such conditions, the nature and role of hydrological forecasts also change from a purely hydrological state to a thoroughly interdisciplinary one. The unique feature of the use of isotope hydrology technology is the quantitative expression of changes in water reserves and their dependencies with potential natural and human factors, which allows a set of facts to be presented for the reasons for the reduction of water resources and to determine the hidden effects of this reduction at the scale of the basin and the whole country. This technique can help to gradually solve the problems of water management and achieve a stable situation by assessing the condition of Iran's water resources, identifying the main issues, and then developing an appropriate strategy and management.

Stable Isotope Hydrology Research in Iran

The application of isotope hydrology for the management of water resources has advanced significantly on a global scale in recent years. However, it is noteworthy that research in this field in Iran is still limited and in its early stages. Despite the potential benefits of these techniques, their application and integration into water resources management practices and macro-level decision-making processes in the country are limited by a lack of comprehensive research and data utilization. This highlights a crucial gap in fully leveraging isotope hydrology techniques to enhance water resources management strategies and to inform key national decisions in Iran. Addressing this limitation through increased research and data utilization could significantly improve the effectiveness and sustainability of water resources management practices in the region. The first study was conducted in 1975 to determine the origin of saline groundwater in the country's south (Zak et al., 1975). An overview of isotope hydrology in Iran and the first Iranian meteoric water line by Shamsi (Shamsi et al., 2014), emphasizes the need for additional facilities to address essential concerns. Dogančić (Dogančić et al., 2020) and Heydarizad (Heydarizad et al., 2021) both concentrate on using stable isotope analysis in particular regions. While Heydarizad was investigating the spatial distribution of stable isotopes in precipitation and groundwater across the country, Dogančić was using this information to characterize the hydrogeological features of Kazeroon City. By examining the chemo-isotopic properties, geothermal activity, and water source of thermal springs in the Damavand volcanic region, Bagheri (Bagheri et al., 2020) adds to this field of study. Together, these studies show how stable isotope analysis can be used to understand and manage Iran's water resources. Osati carried out hydrological monitoring of around 350 water samples from precipitation, river water, and karst springs in the upper portion of the Karkhe River basin. This was done by considering the significance of the karst springs in the Zagros Mountain range and their significant contribution to the supply of agricultural and human needs in western and southwestern Iran. An examination of hydrochemical and isotopic hydrological data revealed a local meteoric water line that is located between the Mediterranean and global mean water bodies (Osati et al., 2014). Hydrogeochemistry and stable isotopes (^{18}O and ^{2}H) have been used to study the impact of several recharge sources on the chemical development of an urban aquifer, Behbahan Plain, southwest of Iran. Daneshian demonstrated that the dissolution of gypsum and a small amount of halite, dedolomitization, limited normal and reverse cation exchange, and mixing were the main hydrogeochemical processes in the aquifer (Daneshian et al., 2021). The stable isotopic composition ($\delta^{18}O$ or δD) of precipitation and karstic water resources in the Qori Meydan Plain (QMP in northeastern Iran) were investigated for the first time (Mohammadzadeh 2017).

Stable isotope hydrology appears to be a valuable tool for managing Iran's water resources overall. However, further study is needed to properly comprehend the country's water resources and create efficient management policies.

Conclusion

The management of Iran's water situation depends significantly on isotope hydrology since it offers important insights into the origin, age, quality, and water flow in subterranean aquifers. By tracing the movement of water in the hydrological cycle using stable and radioactive environmental isotopes, this nuclear approach makes it possible to investigate underground water sources, determine their source and recharge, evaluate their sensitivity to pollution, and more.

Here are some recommendations for policymakers and managers of water resources about the use of isotope hydrology based on the knowledge currently available:

To improve the management of water resources, policymakers should support and promote the application of isotope hydrology. It includes funding studies, supporting educational initiatives, and promoting cooperation between scientists, decision-makers, and water resource managers.

It is essential to increase the understanding of stakeholders, including scientists, politicians, and managers of water resources, about the benefits of isotope hydrology. Workshops, seminars, and other educational initiatives emphasizing the efficient applications of isotope hydrology in water resource management could help accomplish this.

Planning procedures and strategies should be considered in the results of isotope hydrology studies. It can assist in directing choices about sustainable development, pollution avoidance, and the management of water resources.

To benefit from local successes and experiences in advancing isotope hydrology for water resource management, it is necessary to work in tandem with global institutions such as the International Atomic Energy Agency (IAEA).

To gain a better understanding of water supplies and their vulnerabilities, policymakers should fund long-term monitoring and research initiatives that utilize isotopic hydrology techniques. This can guarantee the sustainable management of water resources and assist in shaping future policy decisions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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